

INTENSITY OF RECURVING TYPHOONS

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1. INTRODUCTION

Research is presently being conducted at the Navy Weather Research Facility, with a view towards improving longer-range (up to 3 days) prognoses of western North Pacific typhoons. Reliable warnings available 3 days in advance are highly desirable and often indispensable for typhoon evasion by ships, for disaster planning by naval facilities and many other coastal installations, as well as for optimum ship routing. It is hoped that the typhoon analog techniques developed at the Navy Weather Research Facility and certain types of upper-air analyses and prognoses prepared by the Fleet Numerical Weather Central at Monterey, California, will lead to an improvement in the prognostic tracks of typhoons. On the other hand, there is a good chance that these techniques and/or charts may prove less useful in predicting the future intensity of a typhoon in a large fraction of the cases (except of course, such well-known events as weakening of tropical cyclones when coming under the influence of an upper cold-core trough, etc.).

Typhoons that move from the tropics in a northwesterly direction and then show signs of recurving in the general direction of the Japanese Islands (and adjacent ocean areas) appear to be of particular importance. For this reason, a brief statistical study was initiated with the intent of obtaining climatic guidance regarding intensity changes in recurving typhoons.

1.1 Material Used in Study

The information used in the study -- typhoon locations and their maximum winds -- was extracted from a computer printout of typhoon data covering the period 1945-1968 furnished by the Navy Weather Research Facility. In the earlier years of this 24-year period, reports of typhoon intensity were in many instances very irregular from one observation time to the next. Although examples of such irregularity are also found in later years, they are less frequent, suggesting improvement in wind-measuring equipment, notably Doppler radar. Because of these irregularities, only data from the period 1957-1968 was used.

In accord with the intent of this study, each tropical cyclone must have met the following criteria to be included: (a) it had to attain typhoon force at some time; (b) it had to have a history of at least 3 days; (c) it had to have reached at least 30° N. (as recorded in the printout); (d) it had to have an initial westward component of motion and attained typhoon intensity in the tropics; and (e) it had to remain over the open ocean and not cross land such as Taiwan or the Chinese mainland (this limited consideration mainly to typhoons remaining east of longitude 125° E.).

A large sample of recurving typhoons remained after excluding those typhoons that did not satisfy the preceding criteria. These are discussed in section 2.

Those that did not recurve moved between northwest and north striking land in the vicinity of the Japanese Islands.

Most of these non-recurving storms showed a slow decrease or no change of maximum winds with increasing latitude. The exceptions had a rapid decrease or kept increasing in intensity almost until landfall (similar to the Gulf of Mexico storm, Hurricane Camille of August 1969). It appears difficult to predict from climatic information alone the intensity characteristics of such storms. They must be examined individually in the light of the prevailing synoptic weather situation.

2. GENERAL STATISTICS OF RECURVING TYPHOONS

Those typhoons that recurved (66 storms) -- nearly one-third of all typhoons between 1957 and 1968 -- exhibited certain common characteristics with regard to intensity changes.

Table 1 shows that in 43 cases the maximum wind reported for a given typhoon occurred within 12 hours of the time of recurvature. It must however be noted that the exact place of recurvature is probably not known closer than to the nearest 12 hours (different sources of storm-track data disagree to this extent). Table 1 also shows that in 22 cases, maximum typhoon intensity took place one day or more (rarely 2 days) before the time of recurvature. Only once did the maximum wind speed of a recurving typhoon occur as much as one day after recurvature.¹

¹The few cases with slow intensification on long tracks from the southwest, mostly early and late in the typhoon season, are not included. These may have had at least partial characteristics of polar front cyclones.

Table 1. Relation Between Typhoon Maximum Intensity and Typhoon Recurvature for 66 Cases of Recurving Typhoons (1957-1968).

	Number
Max. intensity occurred within 12 hours of recurvature	43
Max. intensity occurred one day or more before recurvature	22
Max. intensity occurred one day or more after recurvature	1
Total	66

We may conclude that virtually all typhoons reached their peak intensity at, or a little before, the point of recurvature and subsequently decreased at some variable rate.

It is useful, for prediction purposes, to further examine the statistics on the wind speeds of typhoons during recurvature. Table 2 contains such information. On the left we find the well-known seasonal variation in the latitude of typhoon recurvature -- moving north and south with the general circulation. The range of the latitude of recurvature is very large in each month, indicating the variable influence of the synoptic situation on specific storms.

The tabulation on the right of table 2 is of interest in that the mean wind speed of a recurving typhoon is approximately 125 knots in all months except August when typhoons tend to be somewhat weaker.

The data also show that typhoons that recurved during the off-season months (November-May), and that survived as far as

30° N. after recurvature, had maximum winds of at least 100 knots at some time during their existence.

Table 2. Some Characteristics of Recurving Typhoons (66 cases, 1957-1968).

Month	Recurvature						Number of Storms
	Latitude (°N.)			Wind Speed (knots)			
	Mean	Max.	Min.	Mean	Max.	Min.	
June-July	25	33	19	125	170	80	6
Aug.	29	34	24	105	140	70	10
Sept.	26	30	22	125	170	90	18
Oct.	24	31	17	120	150	75	19
Nov.-May	20	25	14	125	150	100	13

3. DECREASE OF TYPHOON INTENSITY

The data show a wide difference of decrease of typhoon wind speed with latitude. One may normalize these differences with respect to the strongest intensity attained by the typhoons. Consider, for instance, the case of Typhoon Kit in June 1966 presented below:

Day/Time	Lat. (°N.)	Wind Speed (kts.)	% of Max. Wind	Heading
25 12Z	16	120	71	330°
26 12Z	22	170 (max.)	100	020°
27 12Z	28	120	71	035°
28 12Z	36	65	38	040°

The velocity during and after recurvature has been normalized by expressing it in percent of the maximum wind speed reached by the typhoon; note that the maximum wind occurred at 12Z on 26 June.

Typhoon Kit reached its westernmost position at 00Z on 26 June; its wind speed at that time was also 170 knots. Thus the maximum winds of Typhoon Kit persisted 12 hours beyond the time of reaching the westernmost point of its track.

When the wind speed changes during recurvature of the typhoons¹ were normalized in the manner just illustrated, it was found that the relation between the wind speed of the typhoons and latitude could generally be represented by a straight line on log paper, or in most cases even on linear graph paper as illustrated by Typhoon Kit in figure 1.

The variation in the slope of the curves of the individual storms fell within a relatively narrow range for most storms, especially for those storms whose tracks did not extend more than 8°-10° of latitude after recurvature. The curves for these storms are well represented by the straight line approximation,

$$V_{\max} / V_{O \max} = 100 - b (\phi - \phi_r) \quad (1)$$

Here V_{\max} is the maximum wind speed at a given time in the typhoon; $V_{O \max}$ is the highest maximum wind speed ever recorded

¹ Because of the additional requirement, that the typhoon track extend at least 2 full days beyond the period of maximum intensity without striking land, the sample size decreased from 66 to 61 cases.

during the life of the typhoon; Φ is the latitude of V_{\max} ; Φ_r is the latitude of recurvature¹; and b is the slope of the straight line. The slope for all storms averages 3.8 with a standard deviation of 0.9; and two-thirds of the slopes fell within one standard deviation.

For storms with tracks extending beyond 8°-10° of latitude after recurvature, the relation tends to be more logarithmic and of the form,

$$V_{\max} / V_{O \max} = 1/(1 + \alpha y), \quad (2)$$

where $y = \Phi - \Phi_r$, measured in degrees of latitude; and α is a constant to be determined.

Figure 2 shows the mean $V_{\max}/V_{O \max}$ curve for all storms with tracks extending up to 16° of latitude beyond recurvature (solid curve). For this distribution α equals 0.056.

A logarithmic relation may have been expected on the basis of an article by Riehl published in the July 1963 issue of the Journal of Atmospheric Science. There it is shown that at a given time for a steady-state typhoon, the following relationship is valid,

$$V_{\max} = \text{const.}/f \quad (3)$$

where f is the coriolis parameter and the constant is determined from the wind speed (tangential) at a chosen radial distance from the typhoon. Of course, this relation does

¹ Except on those cases, where the maximum wind occurred before recurvature, then Φ_r is the latitude at which the storm attained its maximum wind speed.

not refer to successive states of an individual storm since variations with time are not examined. It may be of interest, however, to compare the above relation with the mean curve shown in figure 2 (keeping in mind, of course, that only a select sample of typhoon tracks is being considered). Since,

$$V_{\max} = \text{const.}/f, \quad (3)$$

then also,

$$V_{O \max} = \text{const.}/f_0, \quad (4)$$

therefore,

$$V_{\max} / V_{O \max} = f_0/f \quad (5)$$

One can approximate the coriolis parameter f at a given latitude (β plane approximation) by,

$$f = f_0 + \beta y \quad (6)$$

where f_0 is the value of the coriolis parameter at some fixed latitude, β is the change of the coriolis parameter with latitude (df/dy), and y is the distance going north from the latitude of f_0 . Substituting equation (6) into (5), we obtain,

$$V_{\max} / V_{O \max} = 1/[1 + (\beta/f_0) y] \quad (7)$$

This equation may now be compared with equation (2). Choosing 20° for the latitude of f_0 , $\beta/f_0 = 0.04$. The curve corresponding to equation (7) with $\beta/f_0 = 0.04$ is shown in

figure 2. It is seen that equation (7) gives a somewhat slower velocity decrease with latitude than is actually observed in the mean for recurving storms.

While there are reservations, mentioned earlier, in comparing the two curves in figure 2, it is probably valid to infer that more than the actual non-steady-state behavior of the typhoons is involved in producing the decrease of typhoon intensity with increasing latitude depicted in figure 2.

In an attempt to further explain the rapid decrease of wind speed with latitude in the curve labeled "Mean of Observed Cases" of figure 2, sea-surface temperature charts were examined. These showed that recurving typhoons move nearly at right angles to the sea-surface isotherms in nearly all months. In contrast, storms that do not recurve and that maintain a northwest track move over more nearly constant ocean temperatures. This might help to account for the slower variation in wind speed with latitude usually shown by these storms.

Some numerical typhoon/ocean models show that the minimum sea-level pressure of a typhoon may increase with a lowering of sea-surface temperature. However, typhoon statistics show numerous cases where the maximum wind of typhoons decreased to very low values, while the central pressures were still as low as 970 mb. This and other aspects of the subject matter must be investigated further before a complete physical explanation of the V_{\max} versus latitude relationship in figure 2 can be postulated.

It is hoped that the foregoing information will give the forecaster some idea as to the typhoon intensity variations to be expected during typhoon recurvature.

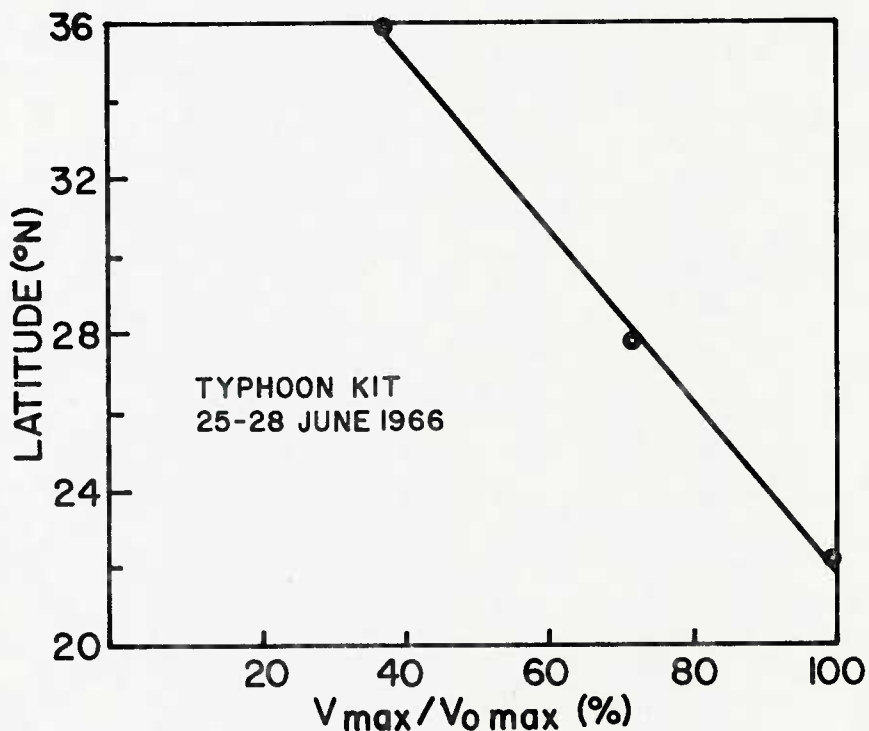


Figure 1. The Maximum Wind (at a given time) of Recurving Typhoon Kit, V_{\max} , Expressed as a Percent of the Maximum Wind Observed for Typhoon Kit, $V_{o \max}$, Versus Latitude.

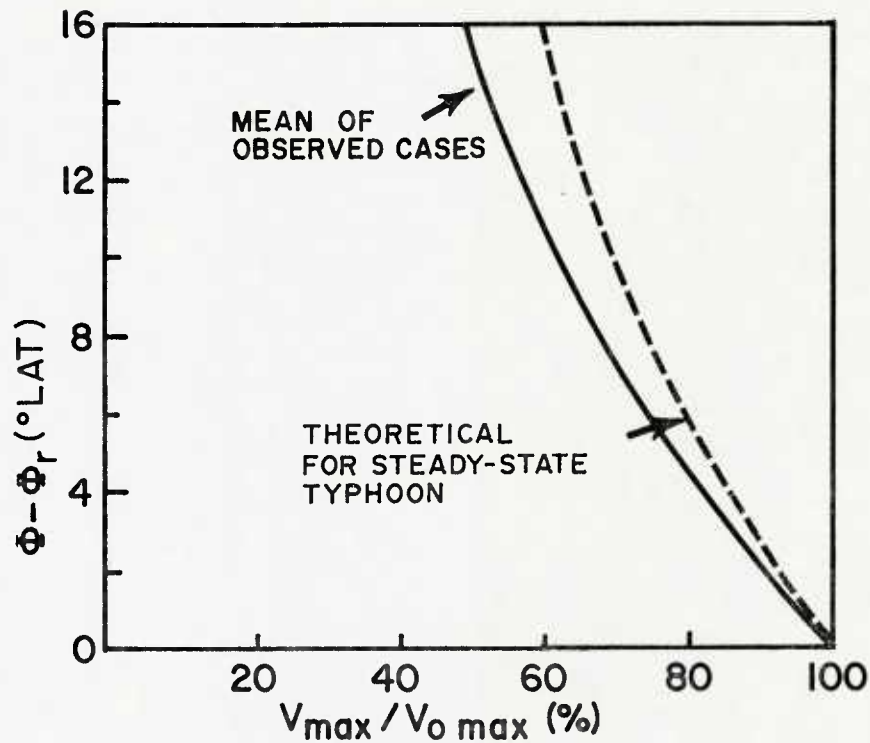


Figure 2. The Maximum Wind (at a given time) of a Recurving Typhoon, V_{\max} , Expressed as a Percent of the Maximum Wind Observed for the Typhoon, $V_{0 \max}$, Versus the Number of Latitude Degrees Following Recurvature. The Solid Line is the Mean of the Typhoons Studied. The Dashed Line is a Theoretical Relationship for a Steady-State Typhoon (see text).